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STUDY OF BLOCK CORROSION IN TRUCK, CARGO, 1-1/4 TON, 6x6, M561

Charles B. Jorden, et al

Coating and Chemical Laboratory
Aberdeen Proving Ground, Maryland

November 1972

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FINAL REPORT

A STUDY OF BLOCK CORROSION IN TRUCK, CARGO, 1-1/4 TON, 6X6, M561

BY

CHARLES B. JORDAN

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NOVEMBER 1972

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13. ABSTRACT

The object of this study was to determine the cause of cavitation/corrosion found on the aluminum block of the Gamma Goat tactical wheeled vehicle (Truck, Cargo, 1-1/4 Ton, 6X6, M561). Severe corrosion was found after this vehicle had been operated less than 10,000 miles when water plus the standard military corrosion inhibitor, 0-I-490a had been used in the cooling system.

Dynamometer tests conducted by the engine manufacturer showed incompatibility of the of the inhibitor and aluminum block at observed operating temperatures of 240°F. A standard simulated service test was modified so that the results correlated with the field observations and with the results of the dynamometer studies.

Under controlled conditions, it was determined that four factors are involved in the block corrosion, these were: (1) composition of the block, (2) phosphate in the corrosion,inhibitor when water is used as the coolant, (3) high engine operating temperatures and (4) configuration of the engine coolant passages which causes restriction of coolant flow in areas of high heat output.

Means of reducing the cavitation/corrosion of the Gamma Goat aluminum block were determined as follows: (1) reduce the operating temperature of the engine, (2) remove the phosphate from the corrosion inhibitor when water is used as the coolant and (3) use ethylene glycol solution as the mandatory coolant for this vehicle year around.

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TABLE OF CONTENTS

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I. INTRODUCTION

Production testing of the Gamma Goat (Truck, Cargo, 1-1/4 Ton, 6X6, M561) under high ambient temperature conditions was conducted at Yuma Proving Ground, Arizona in mid and late 1970. To provide maximum heat transfer efficiency, water plus corrosion inhibitor O-I-490a was used as a coolant, as recommended in TB-750-651. During a breakdown inspection of the engine, (Detroit Diesel Aluminum 3-53), it was discovered that excessive cavitation/corrosion of the aluminum block had occurred in the upper cylinder area (see Photo No. 13 and Figure No. 1). This corrosion resulted in leakage of water into the crankcase in some cases.

The problem was relayed to the engine manufacturer who conducted extensive dynamometer tests on the engine using various coolants. It was found that at 240°F., which was the approximate operating temperature of the engine, cavitation/corrosion occurred when corrosion inhibitor O-I-490a was used in the water. It was also found that a 50% solution of some commercial antifreezes decreased the cavitation/corrosion.

The problem was brought to the attention of this Laboratory, the custodian of O-I-490a and military antifreeze specifications. It was deemed advisable that a study of the cause and mechanism of the corrosion be made.

II. DETAILS OF TEST

A. Structure of Engine.

The engine (Detroit Diesel Aluminum 3-53) contains aluminum block, Alloy No. 355, and three cast iron cylinder inserts. The composition of the block is listed in Table I. Figure 1 represents a drawing of one cylinder area showing the coolant flow path, the area where cavitation/corrosion takes place, and the leakage path of the coolant after corrosion takes place.

B. Dynamometer Tests (Detroit Diesel).

The tests run by Detroit Diesel consisted of a series of 100 hour runs on the Gamma Goat engine at 110 hp, 2800 rpm, with the coolant temperature controlled at 230-240°F. Detroit Diesel stated that these tests, though accelerated, gave close correlation to actual field conditions experienced in summer test work. Tests listed in Table II were conducted and reported to the Project Manager's office.

C. Simulated Service Tests.

These tests were conducted in accordance with ASTM-D 2570, modified by using a water pump from a 1970 Buick. This water pump is an all aluminum pump of an alloy comparable to the aluminum block of

the 3-53 engine. Visible and quantitative cavitation/corrosion caused by the different test solutions was found in the impeller area of the pump which was subjected to the highest liquid velocity. The system was operated under 15 psi pressure. The coolant temperature, controlled by band heaters on the reservoir, was controlled at 240 ± 2°F. The standard duration of the tests was 700 hours. Tests conducted on the simulated service unit are listed in Table III. Excellent correlation between the results of these tests and the results of dynamometer tests was obtained. The results of the simulated service tests also correlated very well with results reported in the field. This study was based on the modified simulated service test for economical reasons. This type of test saves both time and money.

D. Coolant Corrosion Inhibitor System.

The basic corrosion inhibitor system employed in this study was 0-I-490a. This inhibitor is composed of sodium tetraborate, mercaptobenzothiazole (MBT), and disodium phosphate. The sodium tetraborate provides the buffered alkalinity, the MBT is present primarily to provide corrosion protection to copper and copper alloys, the disodium phosphate was added to the system in 1965 to provide protection to aluminum components. These same ingredients are widely used in commercial coolants and derivatives are used in MIL-A-46153, the new single package antifreeze specified for Army use. Tests in this study were conducted in water solution with varying amounts of phosphate, and with and without the MBT additive.

III. RESULTS OF TEST

A. Dynamometer Tests (See Table II and Photos 14 thru 17).

These tests showed that water plus 0-I-490a corrosion inhibitor gave severe cavitation/corrosion of the aluminum block in the area of the block below the liner flange counterbore. A 50% ethylene glycol solution without inhibitor gave only slight signs of cavitation/corrosion. Tap water without inhibitor did not cause cavitation/corrosion. Commercial inhibitors in water caused varying degrees of cavitation/corrosion. Inhibitor No. 1 caused approximately 1/3 the corrosion evidenced when 0-I-490a was used. This inhibitor was analyzed and found to contain the same ingredients as 0-I-490a, but in approximately 1/3 of the concentration. Inhibitor No. 2 showed only slight cavitation/corrosion. One hundred percent ethylene glycol was similar to 50% glycol, however the poor heat transfer properties resulted in oil sludging and poor cylinder condition.

B. Simulated Service Tests (See Table III and Photos 1 thru 12).

The first tests showed that there is excessive cavitation/corrosion of the aluminum pump in the area of the impeller when water plus 0-I-490a is run at 240°F. A 50% solution of MIL-A-46153 gave no

cavitation/corrosion nor did a 50% solution of a commercial antifreeze solution which contained a corrosion inhibitor package similiar to that found in MIL-A-46153. When phosphate was removed from the inhibitor, there was only very slight corrosion in a water-borate inhibitor solution. If the phosphate is doubled, weight loss on the aluminum test specimen in the reservoir is increased and severe cavitation/corrosion is experienced. If the phosphate is halved, weight loss in the reservoir test specimens is sharply reduced, but severe corrosion is still experienced. When mercaptobenzothiazole (MBT) was removed from the O-I-490a, excessive corrosion was still evident. As shown in Photos 5 and 9, if the test temperature is lowered to 220°F., no cavitation/corrosion occurs with phosphate present.

IV. DISCUSSION AND CONCLUSIONS

All tests showed that there would be a problem with the aluminum 3-53 engine if water plus O-I-490a were used as a coolant. This problem occurred due to the incompatibility of the aluminum block with O-I-490a at the high operating temperature of the Gamma Goat. The phosphate appears to be the culprit in the O-I-490a inhibitor. This phosphate was originally added to the inhibitor formulation to protect aluminum in the cooling system, and the inhibitor performed satisfactorily for many years in all types of vehicles in all climatic areas. The value of the phosphate is based on the formation of a thin protective coating on the aluminum which is more durable than the aluminum itself. The high temperature operation evidently precludes the formation of this hard coating, and the coating which is formed in easily removed, exposing the bare metal to attack. The borax and MBT portions of the inhibitor do not promulgate this type of phenomenon.

The composition of the aluminum block (Table I, Appendix A) makes it highly susceptible to cavitation/corrosion. The high silicon content and relatively high iron and copper content are considered the primary causative factors.

An investigation was made of the M551 (Sheridan) engine, 6V53AT, which has the identical metal composition to the aluminum 3-53 engine. More than 100 used blocks located at Anniston Army Depot, Alabama, were inspected without any evidence of block corrosion. Based on the assumption that high operating temperature occurred in some of the vehicles and since no cavitation/corrosion was found this would indicate that the configuration of the aluminum 3-53 coolant passages may be a contributing factor to the corrosion found in the 3-53.

The coolant flow of the 3-53 is more restricted at the 'hot-spot' adjacent to the cast iron liner. This fosters nucleate boiling, which results in bubble formation in the hot areas. These bubbles implode and cause metal cavitation at the point of the metal surface to which they are momentarily attached. Since the operating temperature of the vehicle approaches the boiling point of the water (247°F. at 15 psi) this

nucleate boiling takes place more readily when water is used as a coolant than when ethylene glycol is used as a coolant. (A 50% solution of ethylene glycol boils at 264°F. at 15 psi.) Thus a 50% ethylene glycol antifreeze solution will cause less cavitation/corrosion than water and is safer to use in a high heat output engine, engine, even though the specific heat of the antifreeze solution is only about 0.9 compared to water which has a specific heat of 1.0. If the operating temperature of the vehicle is lowered (such as demonstrated in the tests which were run at 220°F.), less cavitation takes place.

The restricted flow below the liner flange counterbore also causes an increase in velocity of the coolant which flows through this area. This will increase metal erosion and metal particles which are present will be more easily removed from this area of restricted flow.

Part of the corrosion may be electrolytic due to the galvanic cell which would be present due to the close proximity of the aluminum block and the cast iron sleeve. This type of corrosion was not judged to be of a magnitude which would cause the difficulty found in the present situation.

A summary of the causes of the cavitation/corrosion of the aluminum 3-53 block is as follows:

1. High operating temperature.

2. Aluminum metal alloy (with high silicon, iron, and copper content) more susceptible to cavitation/corrosion at high temperatures.

3. Unusual action of phosphate at high operating temperatures in the presence of water.

4. Higher temperature in upper cylinder area.

5. Restricted coolant flow and increased velocity of flow in the area of the liner flange counterbore.

6. Nucleate boiling of water at 240°F.

7. Electrolytic cell set up between aluminum block and cast iron sleeve.

A positive effort was made by the vehicle manufacturer to reduce the operating temperature of the Gamma Goat. A shroud was installed near the engine which redirects the air flow across the engine to give better cooling efficiency. Also the No. 65 fuel injector was reduced to a No. 50 injector to decrease the amount of fuel injected into the cylinders. These modifications reduced the operating temperatures in ambient climates about 10 to 15°F below those temperatures previously experienced. This reduction in temperature should decrease the observed cavitation/corrosion.

Based on the dynamometer and simulated service tests, a recommendation was made to the M561 project manager's office that a 50% solution of MIL-A-46153 be used in all Gamma Goats in the field. Subsequently, a directive was issued to this effect. During the past year, since the implementation of this policy, there have been no reports of cavitation/corrosion in the Gamma Goat engine block.

Work is continuing on the development of an inhibitor system which will perform satisfactorily in this vehicle when water is used as a coolant.

V. RECOMMENDATIONS

Based on all studies conducted to date it is recommended that a 50% solution of antifreeze meeting MIL-A-46153 continue to be used as the coolant in all climates in vehicles containing the Detroit Diesel Aluminum 3-53 engine, particularly the Gamma Goat (Truck, Cargo, 1-1/4 Ton, 6X6, M561).

VI. REFERENCES

1. Federal Specification, 0-I-490a, Inhibitor, Corrosion, Liquid Cooling System, 26 April 1965.

2. Federal Specification, 0-A-548, Antifreeze, Ethylene Glycol, Inhibited, 30 December 1958.

3. Military Specification, MIL-A-46153, Antifreeze, Ethylene Glycol, Inhibited, Heavy Duty, Single Package, 19 October 1970.

4. Technical Bulletin, TB-750-651, Use of Antifreeze Solutions and Cleaning Components in Engine Cooling Systems, 22 January 1971.

APPENDIX A

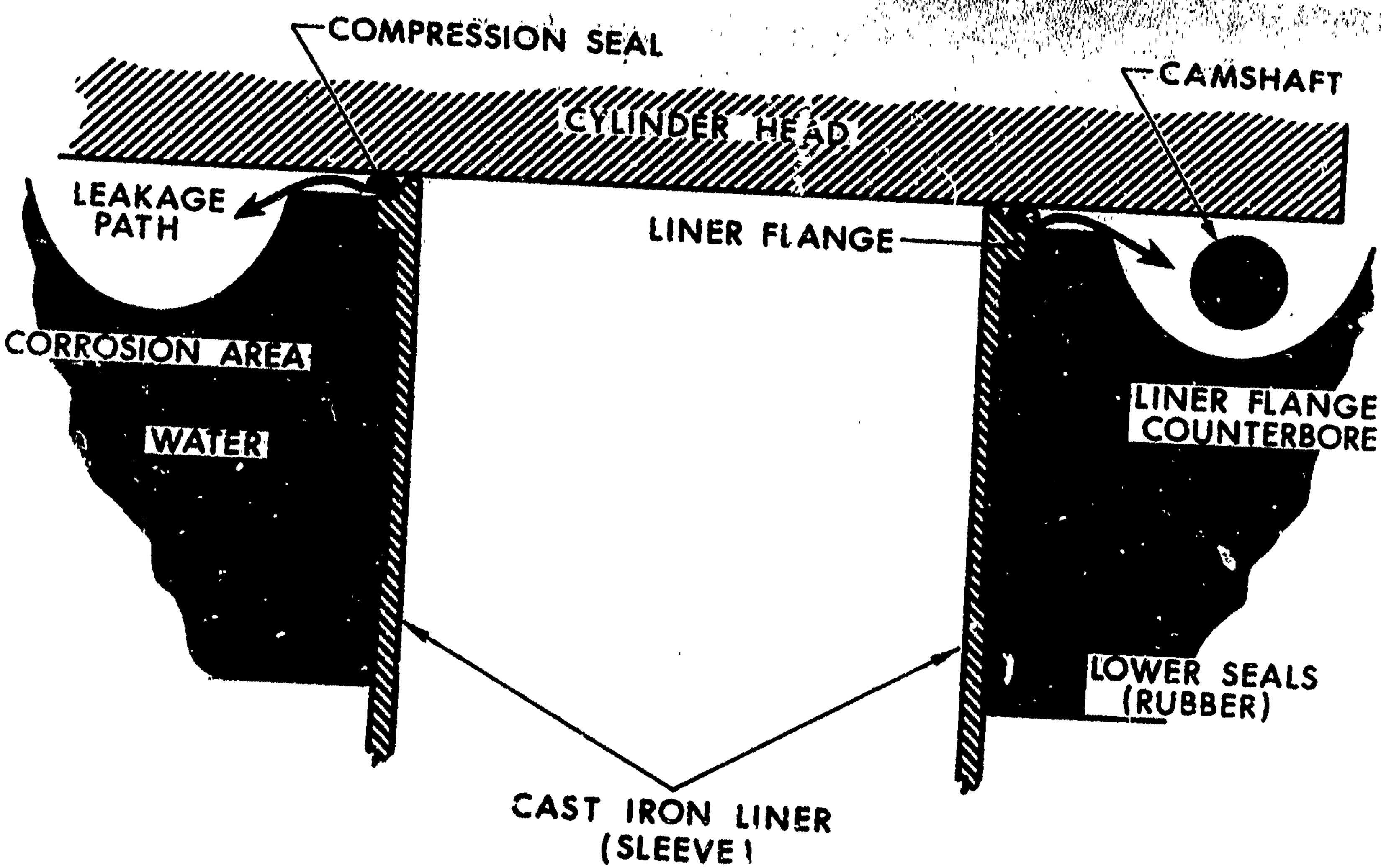


Figure 1. Cross-section of Gamma Goat Cylinder.

APPENDIX B

TABLE I

Composition of Aluminum Block in Truck, Cargo, 1-1/4 Ton, 6X6, M561*

Metal[1/]	Percent
Silicon	5.80
Chromium	0
Copper	1.55
Lead	0.56
Zinc	0
Magnesium	0.60
Iron	0.20
Aluminum	Remainder

[1/] Determined to be Aluminum Alloy No. 355.

*Analysis performed by Materials Laboratory, Tank Automotive Command in Warren, Michigan.

TABLE II

Dynamometer Tests Conducted on the Gamma Goat Engine
By Detroit Diesel

(100 Hrs, 110 HP, 2800 RPM, 230-240°F.)

Coolant	Results
Tap water	No cavitation/corrosion
Tap water plus O-I-490a	Severe cavitation/corrosion
50% antifreeze, O-A-548, Type II	Very slight cavitation/corrosion
100% antifreeze, O-A-548, Type II	Very slight cavitation/corrosion
Tap water plus commercial corrosion inhibitor No. 1[1/]	Moderate cavitation/corrosion (1/3 of O-I-490a)
Tap water plus commercial corrosion inhibitor No. 2[2/]	Very slight cavitation/corrosion
50% antifreeze, MIL-A-46153	Very slight cavitation/corrosion
50% antifreeze, MIL-A-46153 after 255 hours	Slight to moderate cavitation/corrosion

[1/]This inhibitor contained the same ingredients as O-I-490a but in lesser quantities.
[2/]This inhibitor shows corrosion on cooling system metals at low operating temperatures.

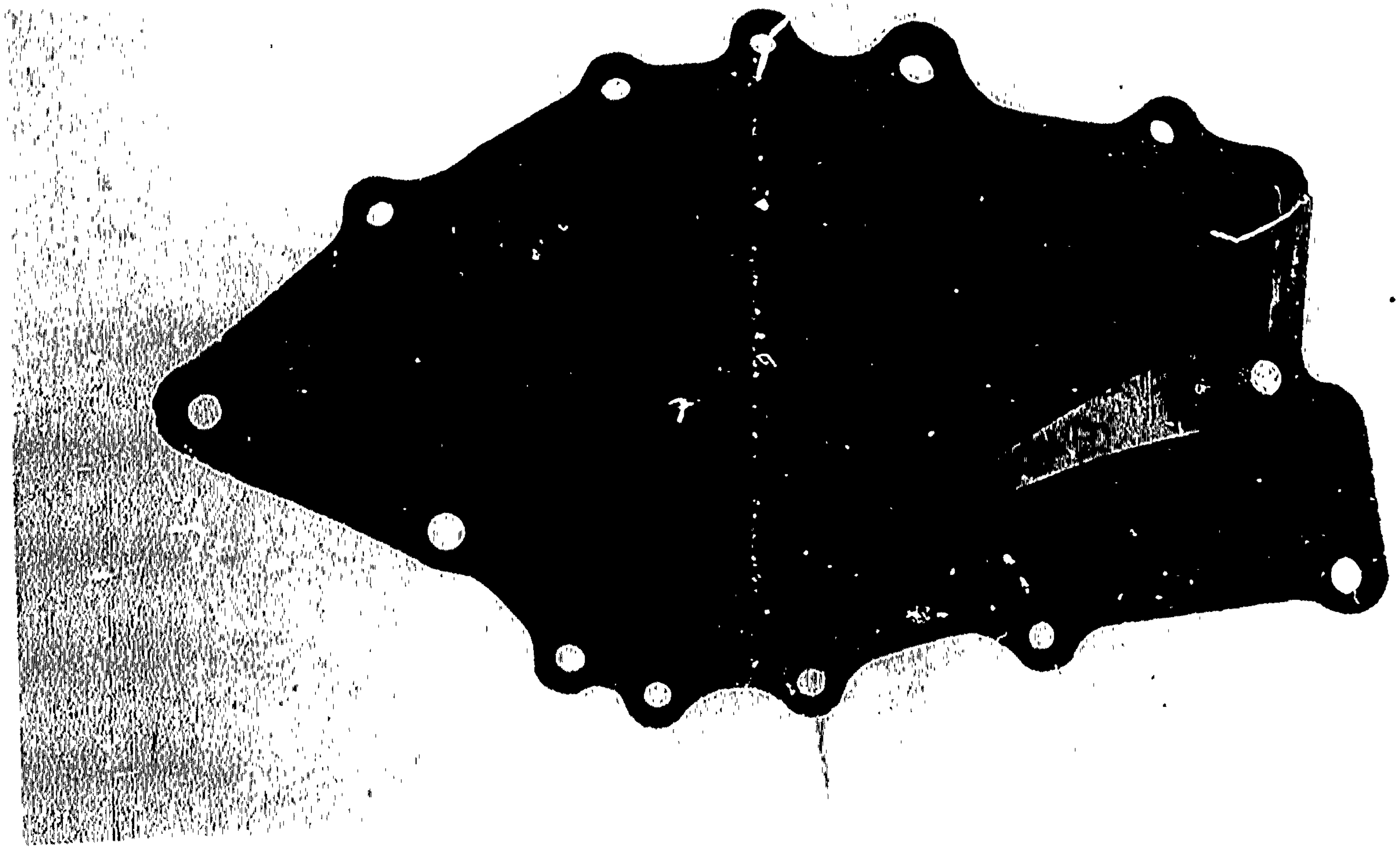
TABLE III

Simulated Service Test Results

Test No.	Test Temp, °F.	Coolant Composition*	Metal Components Pump	Metal Components Radiator	Metal Components Reservoir	Duration, hrs.	Pump Condition
1	240	Water + 0-1-490a	Aluminum	Copper	Aluminum	318	Moderate cavitation/corrosior
2	240	Water + 0-1-490a	Aluminum	Copper	Aluminum	717	Severe cavitation/corrosion
3	240	50% MIL-A-46153	Aluminum	Copper	Cast Iron	1020	No cavitation/corrosion
4	240	50% commercial antifreeze	Aluminum	Copper	Cast Iron	1064	No cavitation/corrosion
5	220	Water + 0-1-490a	Aluminum	Copper	Cast Iron	700	No cavitation/corrosion
6	240	Water + Borax + Na_2HPO_4	Aluminum	Copper	Cast Iron	712	Severe cavitation/corr
7	240	Water + Borax	Aluminum	Copper	Cast Iron	762	No cavitation/corrosion
8	240	Water + 0-1-490a	Aluminum	Aluminum	Cast Iron	713	Severe cavitation/corrosion
9	220	Water + Borax + Na_2HPO_4	Aluminum	Copper	Cast Iron	721	No cavitation/corrosion
10	240	Water + Borax + 2 X Na_2HPO_4	Aluminum	Copper	Cast Iron	713	Severe cavitation/corrosion (less than #2)
11	240	Water + Borax + 1/2 X Na_2HPO_4	Aluminum	Copper	Cast Iron	700	Severe cavitation/corrosion (less than #2)
12	240	Water + Borax + MBT	Aluminum	Copper	Cast Iron	690	Slight cavitation/corrosion

*All tests solutions made up with ASTM corrosive water containing 100 ppm $SO_4^{=}$, Cl^-, and HCO_3^-.

APPENDIX C



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SIMULATED SERVICE TEST - 318 HRS.
WATER + O-I-490A 240°F./15 LB. PRESSURE
MAY 71 8

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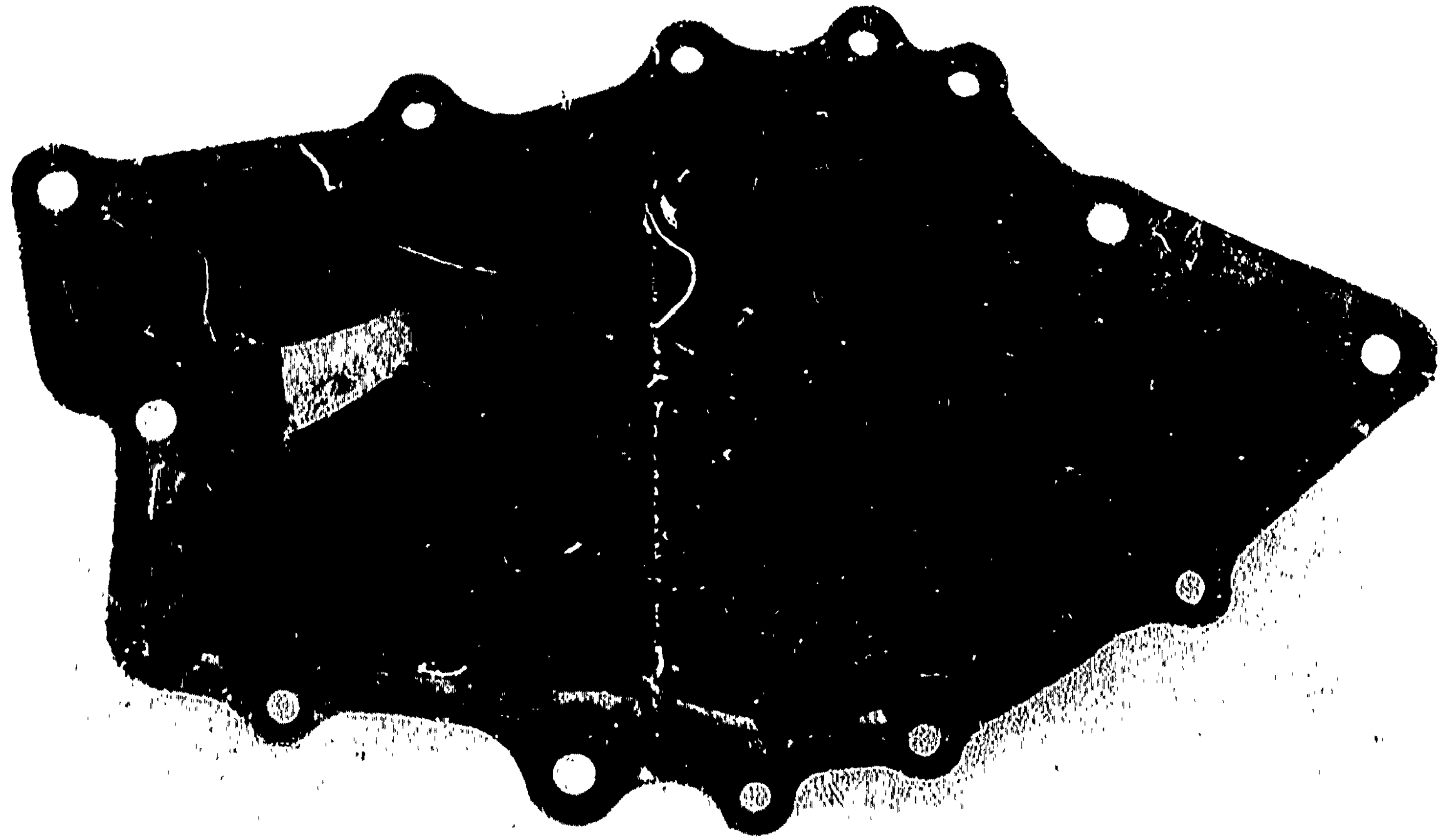
Simulated Service test - 700 hrs.
Water + O-I-490a 240°F/15 lb. pressure
May 71



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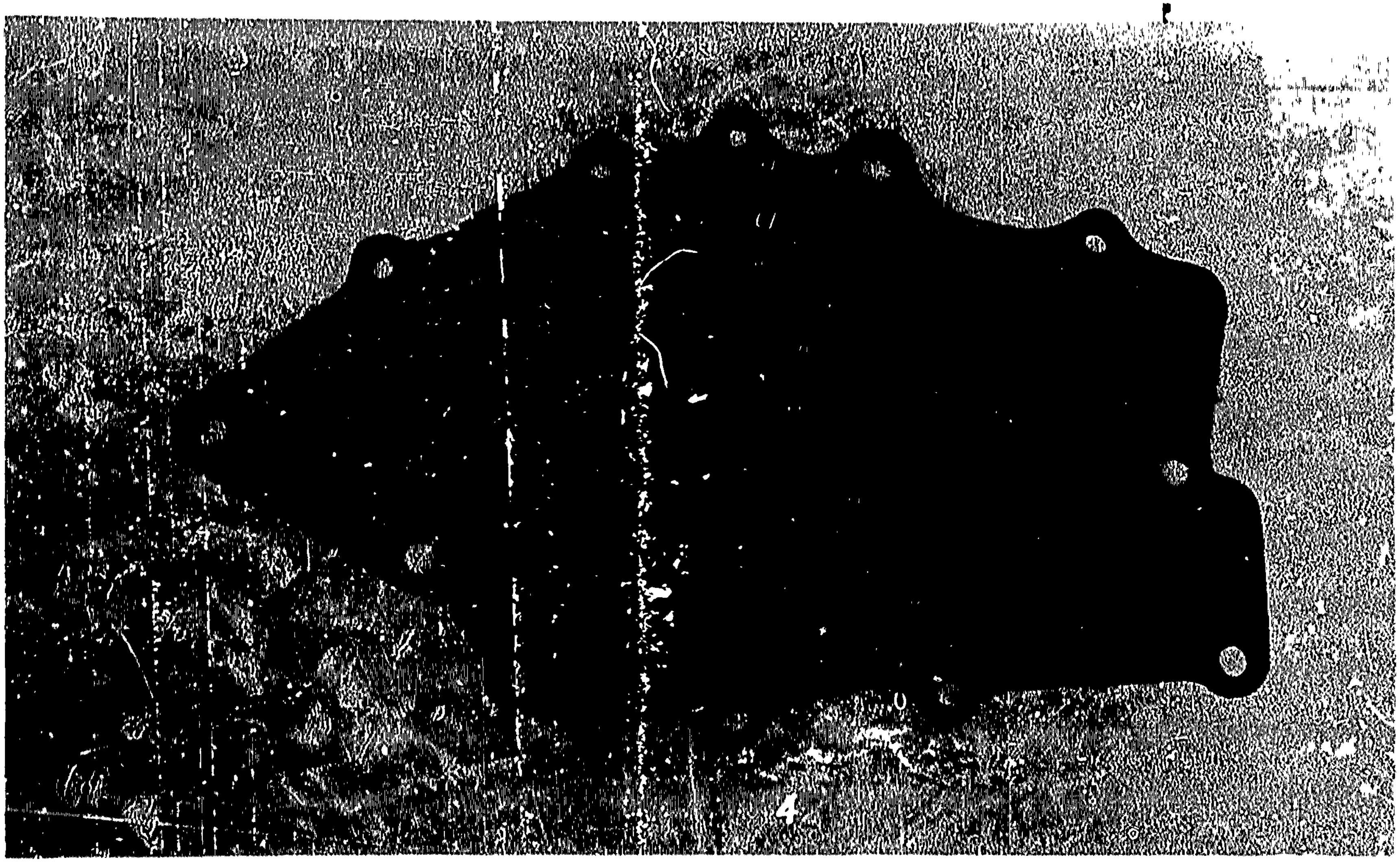
SIMULATED SERVICE TEST - 1020 HRS.
50% MIL-A-46153 240°F/15 Lbs. Pressure
AUGUST 1971

11



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SIMULATED SERVICE TEST - 1064 HRS.
50% PERMA STA 240°F./15 LB. PRESSURE

12 OCTOBER 71

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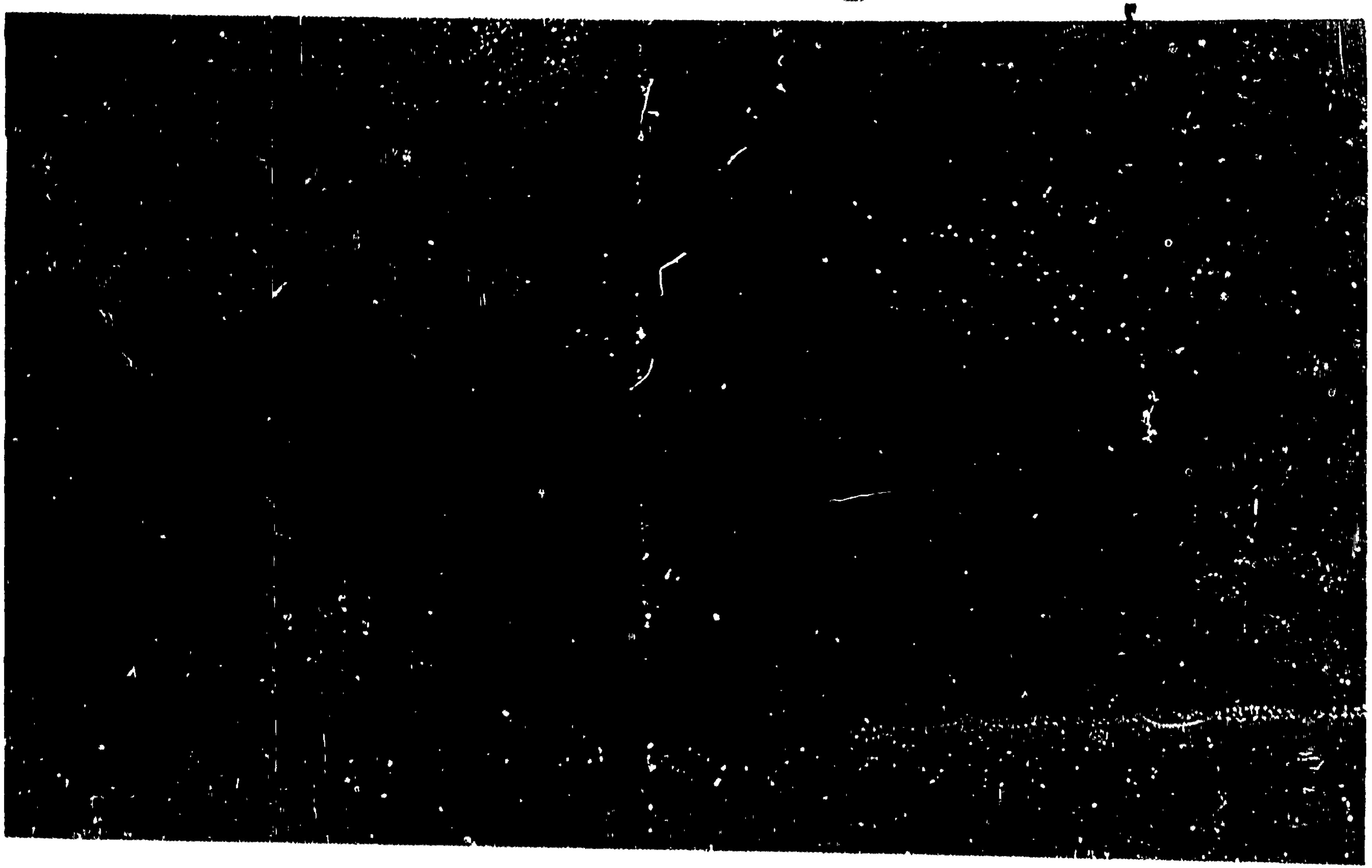
13

Simulated Service Test - 712 Hrs.
Water + Borax + Na_2HPO_4 240°F./15 lb. pressure
February 72



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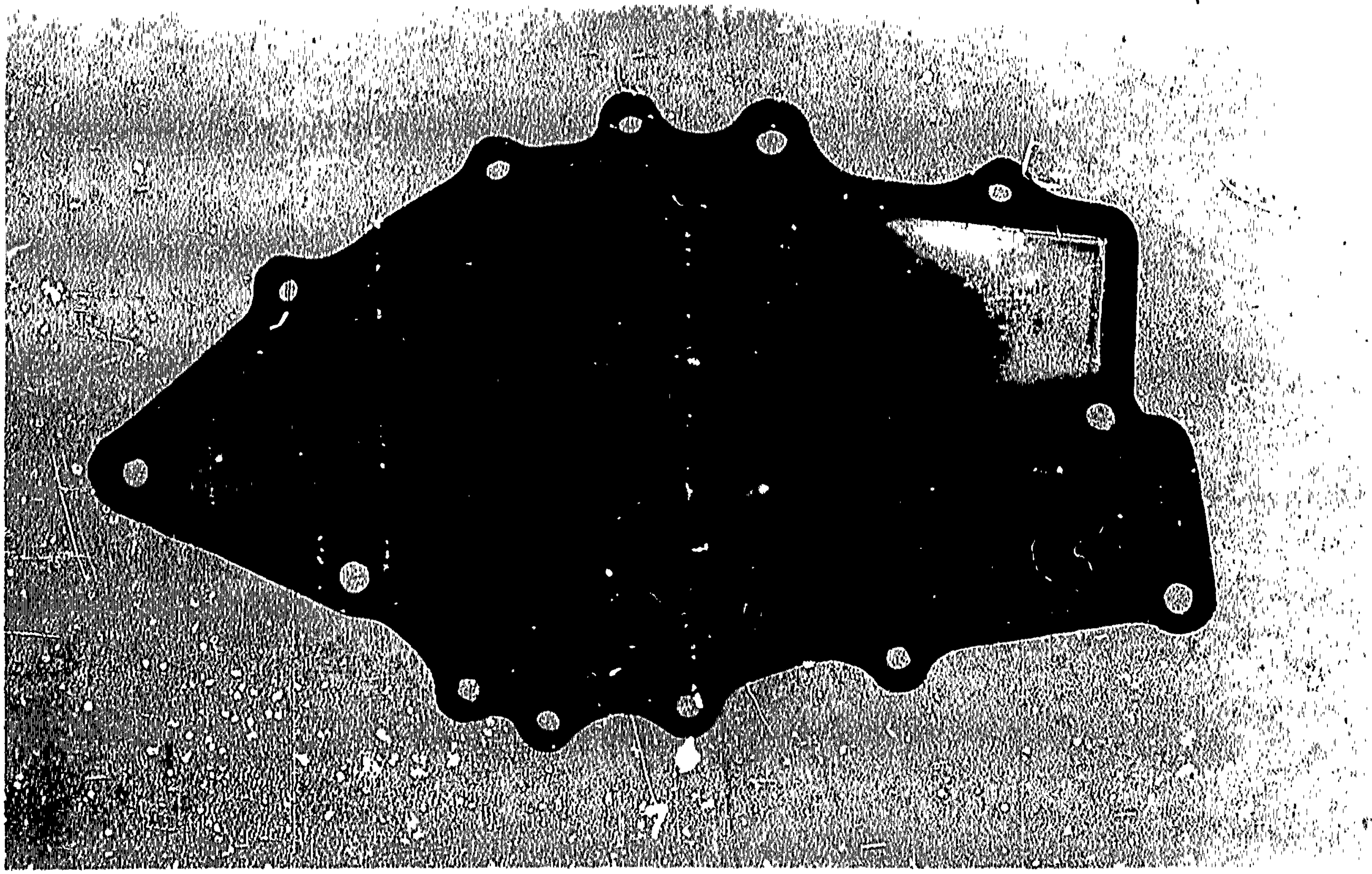
SIMULATED SERVICE TEST - 700 HRS.
WATER + 0-I-490A 220°F./15 LB. PRESSURE
NOVEMBER 71



15

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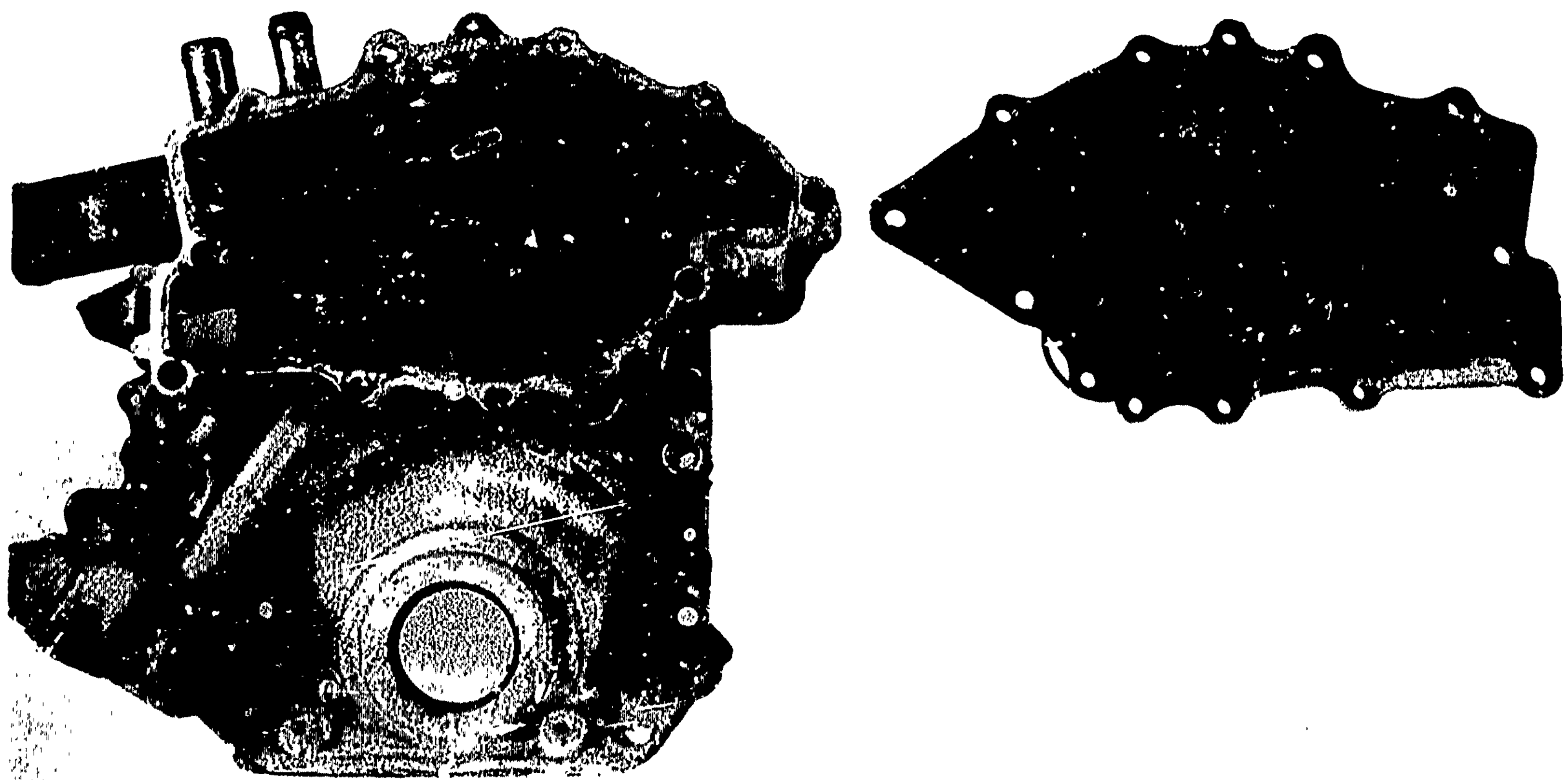
SIMULATED SERVICE TEST - 762 HRS.
WATER + BORAX 240°F./15 LB. PRESSURE
FEBRUARY 72



16

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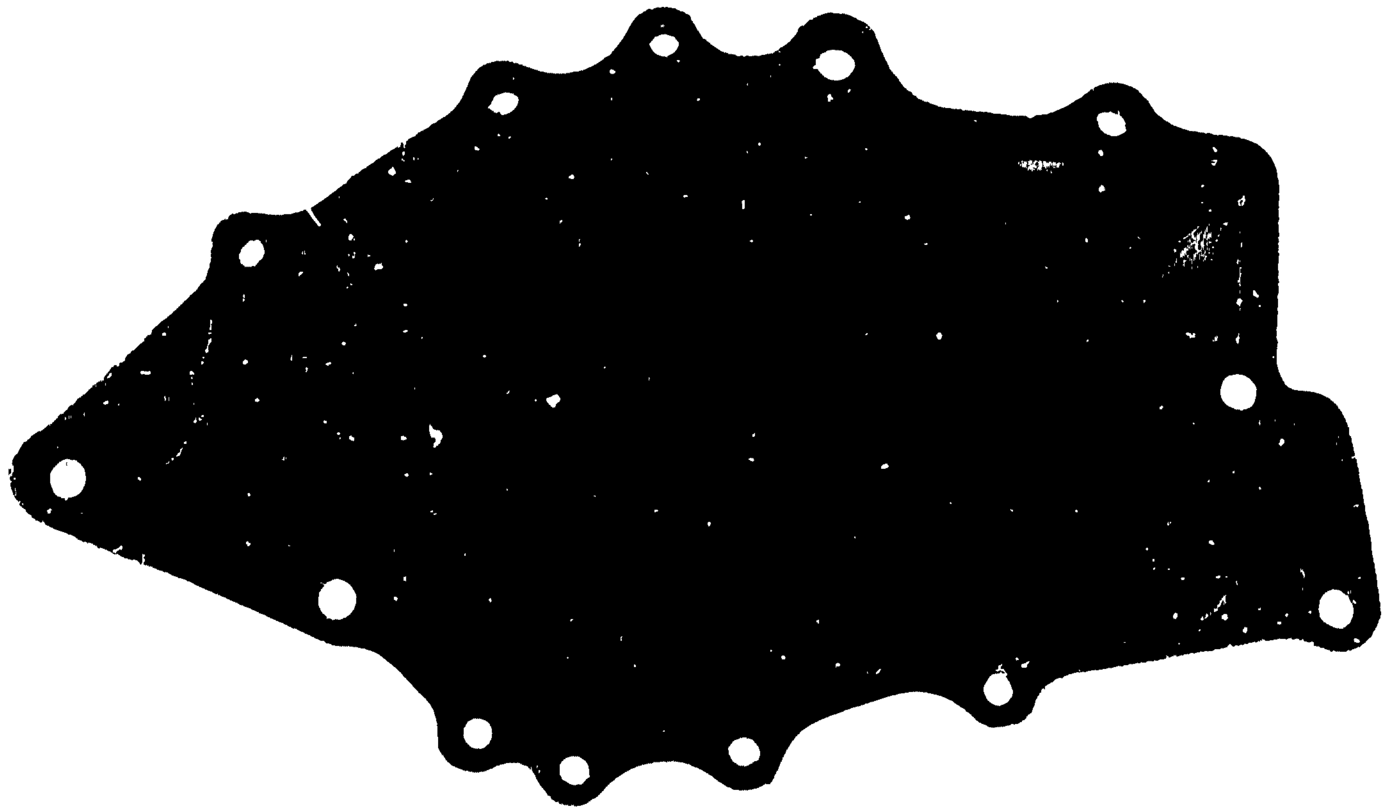
SIMULATED SERVICE TEST - 713 HRS.
WATER + O-I-490A   240°F./15 LB. PRESSURE
MARCH 72



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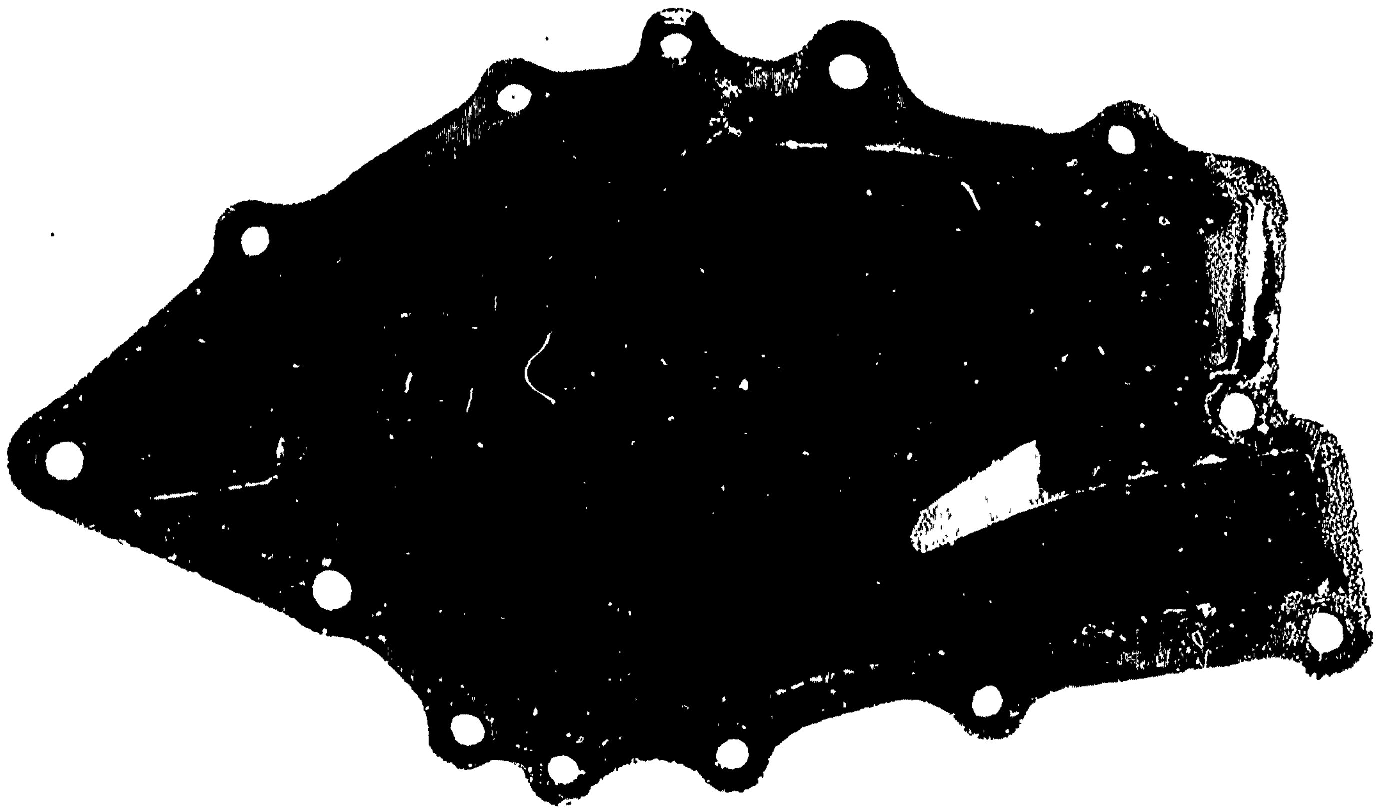
17

Simulated Service Test - 721 Hrs.
Water + Borax + Na_2HPO_4 220°F./15 lb. pressure
March 72



18

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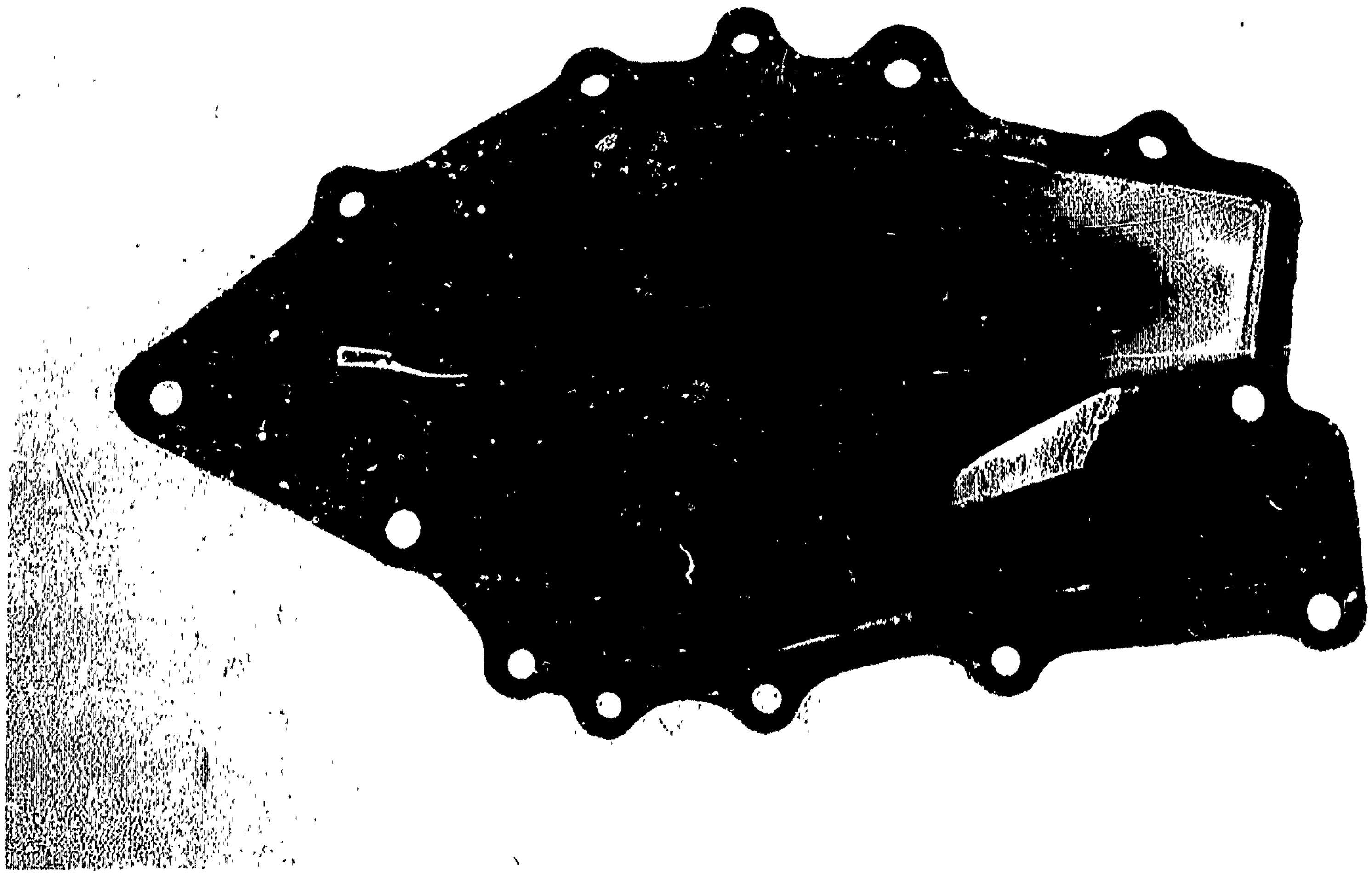
SIMULATED SERVICE TEST - 713 HRS.
WATER + BORAX + 2 X Na_2HPO_4 240°F./15 LB. PRESSURE
APRIL 72



19

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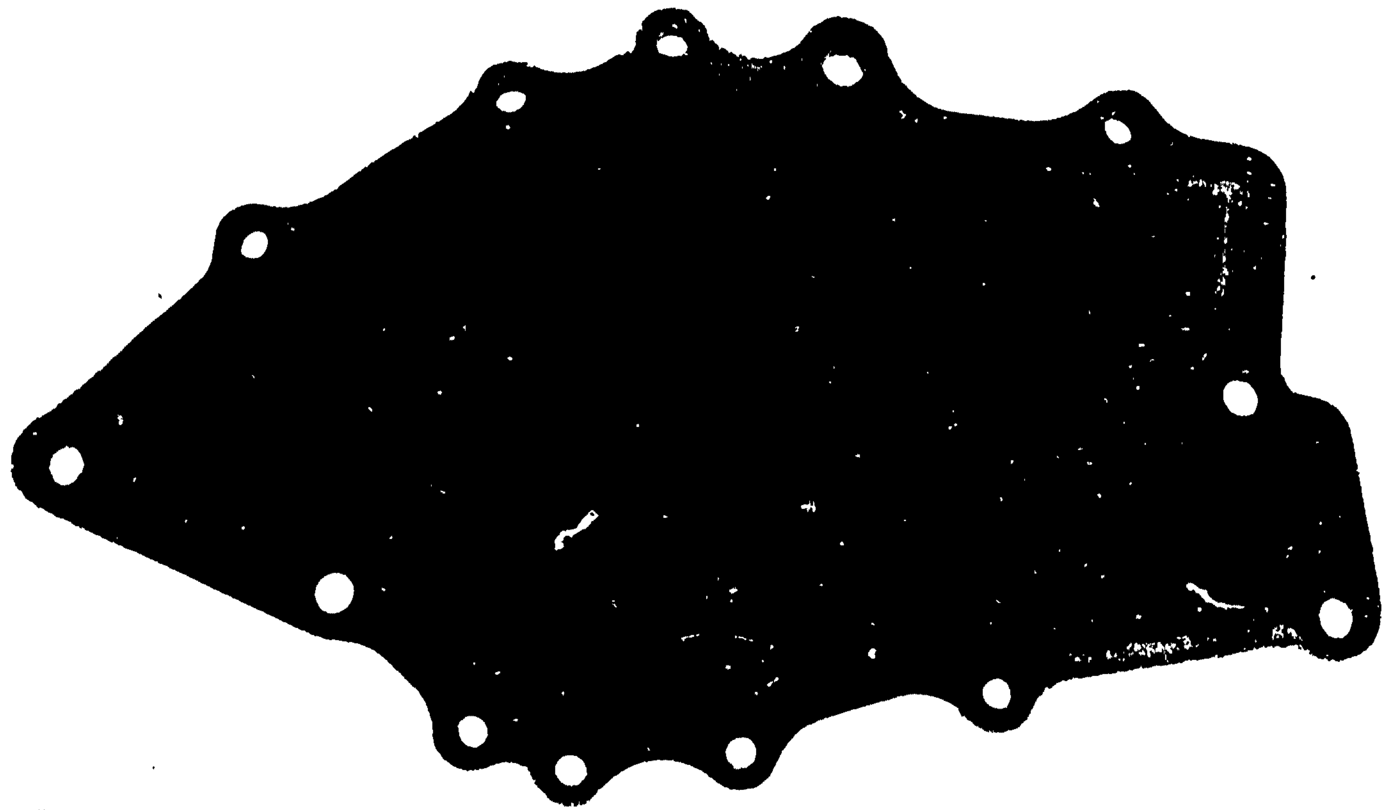
Simulated Service Test - 700 Hrs.

Water + Borax + 1/2 x Na_2HPO_4 240°F/15 lb. pressure

May 72



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20

SIMULATED SERVICE TEST - 690 HRS.
WATER + BORAX + MBT 240°F./15 LB. PRESSURE
JULY 72

13

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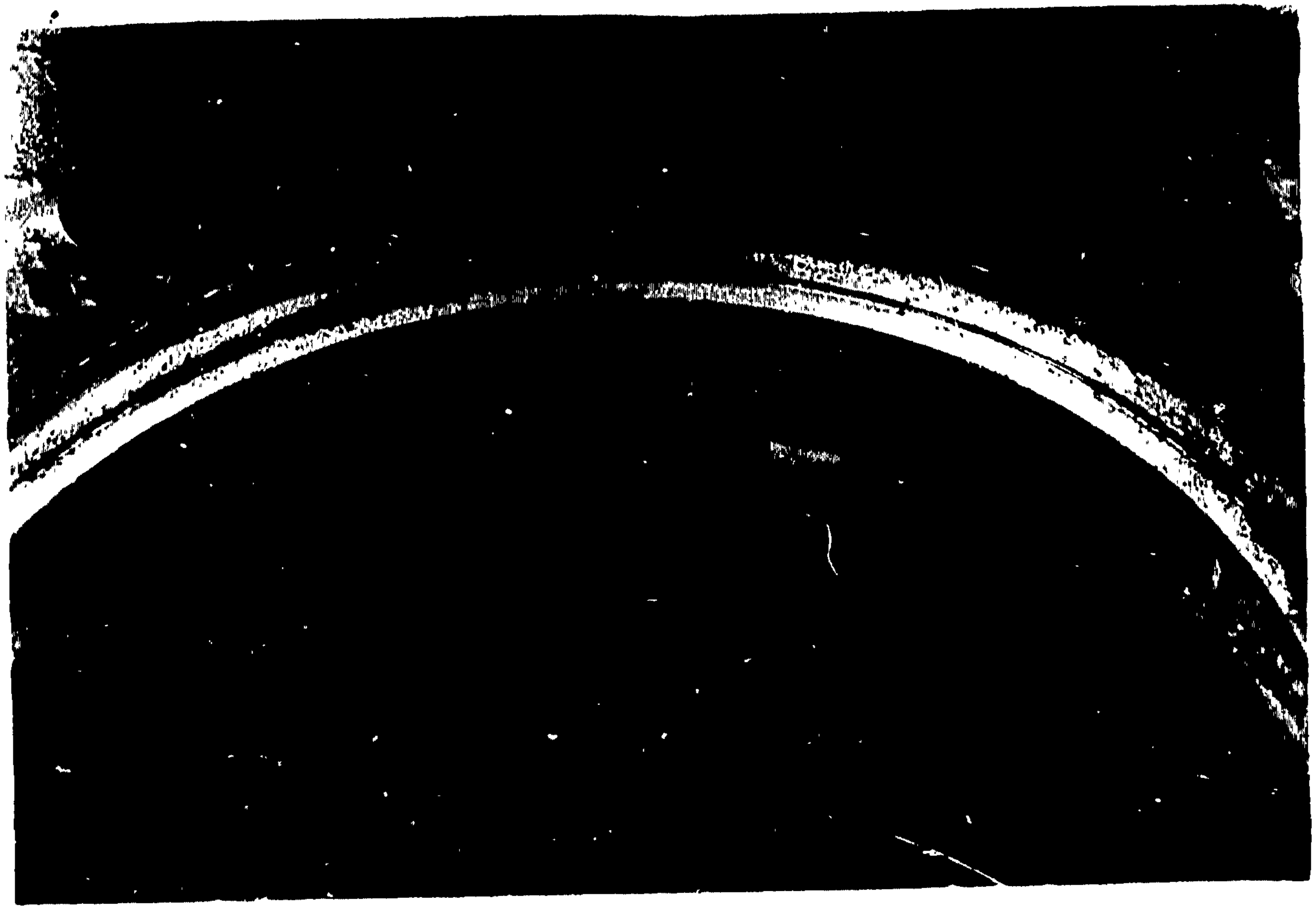
21 CAVITATION/CORROSION OF ALUMINUM 3-53
ENGINE BLOCK FROM THE GAMMA GOAT

14
DETROIT DIESEL DYNAMOMETER TEST
WATER + 0-I-490A
100 HOURS 230° - 240°F.



15
DETROIT DIESEL DYNAMOMETER TEST
WATER + COMMERCIAL INHIBITOR
100 HOURS 230° - 240°F.

1F

DETROIT DIESEL DYNAMOMETER TEST
100% DETROIT TAP WATER
100 HOURS 230° - 240°F.

17

DETROIT DIESEL DYNAMOMETER TEST
50% MIL-A-46153
100 HOURS 230° - 240°F.